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Indirect Wave Load Estimates Using Operational Modal Analysis – Preliminary Findings

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ABSTRACT

Wave loading on offshore structures has proven difficult to quantify through direct full-scale measurements. Therefore, engineers rely on codes and guidelines, numerical simulations, and scaled experiments in the design and as-built evaluation process. In this paper, it is shown that by monitoring the response of the structure and utilizing Operational Modal Analysis (OMA) it is possible to indirectly identify loads, occurring in actual conditions. A method employing modal parameters to establish a response function, which is used to back-calculate the hydrodynamic wave loading of a structure is presented. The process of inverting the system matrices is stabilized by merging the model with linear wave theory and hence constraining the solution to a scaling function of a predefined load distribution. The method is validated through a numerical case study and by wave flume experiments. Both cases are constituted as two-dimensional loading on a semi submerged cantilever cylinder.

KEYWORDS: Wave Loading; Indirect Measurements; Operational Modal Analysis; Offshore Structures

INTRODUCTION

In recent years concerning footage from the North Sea have been fuelling an intensive investigation lead by Mærsk. The recordings show plunging breaking waves at the Tyra field in close proximity to the offshore structures (Tychsen and Dixen, 2016). It was estimated that the wave heights were exceeding the 10 000 year return period for abnormal wave design. Questions have been raised whether the load effect of these extreme waves will compromise the reliability of the structures at sea.

Although much research has been done in the field of abnormal and breaking waves, it is evident that more research is needed in the field of extreme wave loading to offshore structures. Some issues remain elusive as most methods are based on scaled laboratory experiments. When conducting wave lab experiments, scaling effects will inevitable be present and especially in the case of breaking waves (Hughes, 2015).

A new approach - not subjected to scaling limitations for wave load quantification - is presented in this study. By monitoring the response of an offshore structure, the structure itself can be used as a live full scale load cell. This is done by inverse computations from the response of the structure. Limited research has been done specific to this application (Jensen et al., 1992; Perisic et al., 2014), whereas more focus has been given to indirect methods of e.g. fatigue assessment of offshore structures (Noppe et al., 2016; Maes et al., 2016). The indirect load identification of the wave action is a challenging discipline to verify, which may be the reason why little work has been done on this in the past. Input estimation in general is not a new topic as people have worked with this for many years.

In the late 80's Karl Stevens wrote an excellent overview on the topic of indirect load identification (Stevens, 1987). The paper outlines the challenges associated with this field of research, but also its potential. Many different approaches have since been tried out within the field of input identification. Most of the work done in this context are based on cases where the input is well defined and hence capable of verifying the results - either by using impact hammers or by simulation e.g. (Fritzen and Klinkov, 2014; Aenlle et al., 2007; Wang and Chiu, 2003). In resent years input identification using Kalman filters has proven successful (Lourens et al., 2012; Hwang et al., 2009; Naets et al., 2015; Liu et al., 2000; Maes et al., 2017).

In this paper, Operational Modal Analysis (OMA) will be used as a tool for modal identification of the structures in as-build conditions. The result from the OMA is used to make a model representation and this will be the key in deciphering the vibrations of the structure and hence estimate the wave loading.

The mathematical notation used is denoting matrices by a double underline and vectors by a single underline. Superscript* is a complex conjugate and superscript^T is a transposing operation.

THEORY

The response of a linear dynamic system, $\underline{y}(t)$, is defined as the convolution integral between the impulse response function, $\underline{\underline{h}}(t)$ and the a time varying load. (Brandt, 2011). The principle of load identification